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Emission Effects of Inspection and Maintenance at Cold Temperatures

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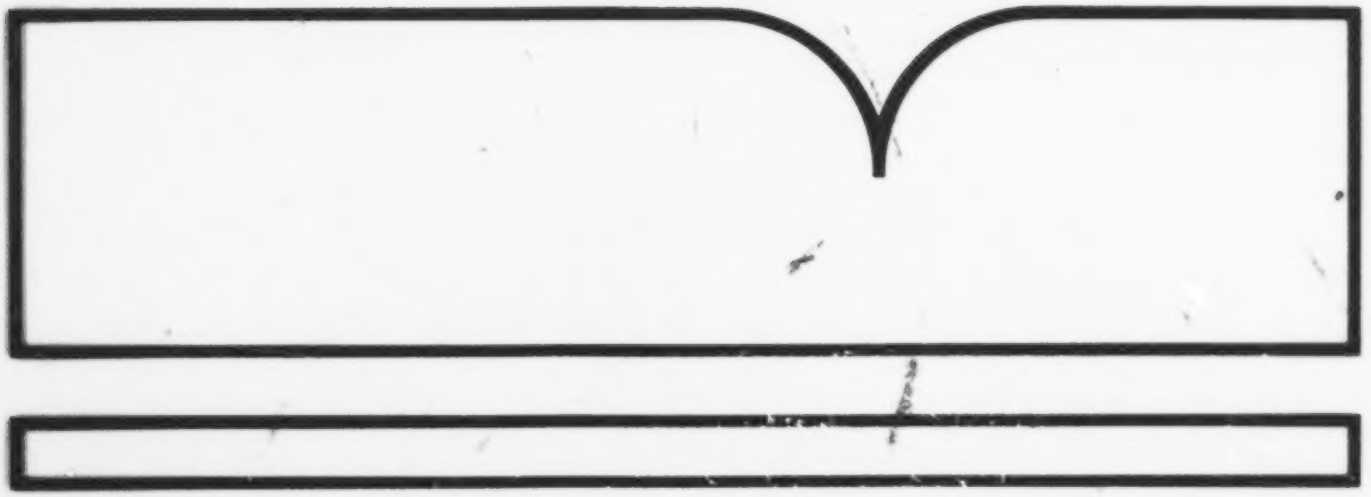

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Technical Report

Emission Effects of Inspection and Maintenance at Cold Temperatures

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16. ABSTRACT

This report discusses the potential effectiveness of Inspection and Maintenance (I/M) programs at reducing carbon monoxide (CO) emissions from vehicles operated at cold temperatures.

Four vehicles were deliberately maladjusted and tuned up to simulate the effects of an Inspection and Maintenance program on vehicles needing emission-related repairs. The results indicate that reductions in carbon monoxide emissions occurred when vehicles with maladjusted idle mixture and disconnected choke assist were tuned up.

Inasmuch as this test program was limited to four vehicles, the conclusions should be viewed as preliminary. However the results indicate that Inspection and Maintenance has the potential for reducing carbon monoxide emissions from in-use vehicles operated at temperatures below 75 F.

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1.0 INTRODUCTION AND SUMMARY

This report discusses the potential effectiveness of Inspection and Maintenance (I/M) programs at reducing CO emissions from vehicles operated at cold temperatures. The EPA has extensively studied the effectiveness of I/M at reducing emissions at 75° F, and has shown that I/M is capable of reducing CO emissions on failed vehicles by about 50% at 75° F. At warm temperatures maladjustment of idle mixture is the most common cause of high CO emissions. At colder temperatures the operation of choke systems causes high CO emissions. However, vehicles which have maladjusted idle mixture may emit more CO in cold temperatures than vehicles without maladjusted idle mixture. I/M would therefore be capable of producing some CO reductions from vehicles operated in cold temperatures. This report centers on how much these reductions might be.

We have concentrated our analysis on CO emission behavior because most CO non-attainment areas have heightened CO air quality problems during the winter. Although HC emissions from vehicles also increase substantially in cold weather, most areas have little or no problem with ozone since the days are short, the sun is often blocked by clouds, and temperatures are cold, all of which inhibit the photochemical reactions which produce ozone. We have also analyzed fuel consumption characteristics in cold temperatures.

Four vehicles were deliberately maladjusted and tuned up to simulate the effects of an Inspection and Maintenance (I/M) program on vehicles needing emission-related repairs. The results indicated that I/M has the potential for reducing CO emissions from in-use vehicles operated at temperatures below 75°F. However, these results and conclusions should be viewed as preliminary until the State of Alaska presents data on the effectiveness using in-use vehicles. The table below shows CO reductions obtained from three of the four vehicles which were tuned-up after receiving tests with idle mixture maladjusted. One of the vehicles had a sealed idle mixture screw which we did not maladjust. Vehicles received other maladjustments, which are discussed in Sections 3 and 4. However, idle mixture is the most important maladjustment and is the only maladjustment summarized.

Table 1

CO Reductions Obtained in Going
From Maladjusted Idle Mixture Configuration
to Tuned-Up Configuration: Average of 3 Vehicles

Test Cycle	Distance	g/mi. Reductions 20°F	g/mi. Reductions 50°F	% Reductions 20°F	% Reductions 50°F
FTP* Composite	7.5 miles	23.8 g/mi	25.1 g/mi	36%	52%
FTP Bag 1 Only	3.59	12.3	48.4	9%	35%
5 min. Idle Warm-Up + FTP Bag 1	3.59	40.2	47.1	30%	59%
5 min. Idle Warm-Up + FTP Bag 1 + Bag 2	7.5**	44.5	43.2	41%	57%

* The actual driving distance on the FTP is 11.1 miles. However, emissions from the 11.1 mile trip are reweighted to reflect the average incidence of hot and cold start trips during the day (57% and 43%, respectively), and an average trip distance of 7.5 miles. In cold climates, these average percentages of hot and cold starts may be different. See Appendix 1 for further explanations of FTP terminology.

** Although this trip distance like that of the FTP is 7.5 miles, the emission results have not been reweighted like the FTP to include any hot start trip results.

The CO g/mi reductions in the table above are nearly the same at 20° as at 50° for the FTP composite and 5 minute idle warm-up plus FTP Bag 1 + 2 test cycles. However, for the shorter test cycles of the FTP Bag 1 and the 5 minute idle warm-up plus FTP Bag 1, the reductions at 20° are significantly less than at 50°. We attribute this relationship to the hypothesis that maladjusting idle mixture changes the air/fuel ratio less at 20° than at 50° for the shorter test cycles, since during a short trip at 20° the carburetor is very rich to begin with because of choke operation. Consequently, fixing the maladjustment has less impact at 20° than at 50°F. This relationship has been confirmed with fuel consumption data. For a detailed explanation of this relationship, see Section 5.1.

The FTP composite CO reduction at 50° (52%) closely matches the 50% reduction in CO emissions obtained from failed vehicles in the Portland, Oregon I/M program. This suggests that our idle mixture maladjustment is typical of in-use vehicles.

2.0 BACKGROUND

The first part of the background section contains a conceptual discussion of why CO emissions are high at cold temperatures. Next, the specific systems which cause the high CO emissions (e.g., choke and idle mixture) are discussed. External factors such as driving habits can also affect the amount of CO produced, so this is discussed in Section 2.3. Lastly, we concentrate on those things which show potential at reducing CO emissions at cold temperatures: new technology on late model cars, block heaters, and I/M programs.

2.1 General Causes of High CO Emissions at Cold Temperatures

Most vehicles even when properly maintained emit substantially more CO at cold temperatures than they do at warm temperatures. There are several reasons for this phenomenon. First, at low temperatures, engine starting requires carburetor choking because of the low volatility of gasoline at low temperatures. Much of the gasoline entering the engine is in excess of stoicheometry and exits the engine as CO. Second, low temperatures also result in longer engine cranking times than would be experienced at warmer temperatures. Like choking, long cranking times can add more low-volatility fuel to the engine, resulting in more incompletely burned combustion products. Third, the choke does not completely open up at the instant the vehicle is started. Depending on what other choke controls are present on a vehicle (electric assist, thermostatic coil, etc.) it may take several minutes for the choke to completely open up. Fourth, internal friction in the drive train and the power required to drive the accessories (heater, wipers) are higher, requiring greater power output from the engine during warm-up. Finally, during engine starting and warm-up the catalyst is cold and unable to operate effectively. All of these factors contribute to high CO emissions in the first few minutes of vehicle operation; in well-maintained cars they have very little effect on CO emissions after vehicles are warmed-up.

On a more general level, there are many sources which may be identified as causing high CO emissions in typically--rather than properly--maintained vehicles at cold temperatures. Some of these sources are "naturally occurring" sources (or design sources) which are, from an engineering standpoint, absolutely essential to start an engine and keep it running initially in cold weather. An example of a naturally occurring source in an engine is the operation of the choke system described in the preceeding paragraph. Operation of the choke system produces high CO emissions, but its operation is necessary to get the engine started.

Other causes of high CO emissions in vehicles at cold temperatures are very similar to the causes of high CO emissions in vehicles at warm temperatures and can be grouped into a single heading: malmaintenance. Malmaintenance can take the form of deliberate maladjustments such as maladjusted idle mixture and choke controls, or can arise through owner neglect of timely maintenance. Examples of this latter type of malmaintenance are plugged PCV valves and dirty air cleaners.

Still other potential sources of high CO emissions in vehicles at cold temperatures are not really within the engine but are external to it, and these are driving habits. For example, at cold temperatures, drivers are likely to warm-up their vehicles at idle for a few minutes before embarking on a trip. This may produce more CO emissions than if the vehicle is simply started and driven in cold weather.

Each of these causes has an effect on the total trip CO emissions coming from a vehicle which is operated at cold temperatures. A detailed analysis of each cause is helpful in understanding how they affect total CO emissions.

2.2 Primary Sources of CO Emissions

2.2.1 Choke Operation

The choke system on most vehicles consists of a choke plate which rotates in the top of the carburetor air horn, a set of linkages attached to the accelerator pedal which control the initial choke plate setting, a choke vacuum break system which opens the choke slightly once the engine is started and an electric or thermostatic assisted choke coil which controls how fast the choke system turns off (opens) from then on. When a vehicle is started in cold weather, the choke plate is closed, creating a high vacuum in the carburetor which draws more fuel into the engine. The choke vacuum break works to open the choke a small amount once the engine has started, so that more air can get into the engine. After the vehicle is running, the coil heats up and gradually opens the choke plate, thereby reducing the vacuum in the intake manifold and the amount of fuel delivered to the engine. At idle, the choke does not fully open until 5 or 6 minutes have passed.* If a vehicle is forced to warm-up more quickly by higher speed/load operation, the choke may open more quickly.

Normal choke operation, therefore, causes high CO emissions since a very rich mixture of fuel in air is needed at low temperatures to get a cold engine started and keep it running. However, a maladjustment of choke controls can also produce very high CO emissions. If the electric assist assembly of the choke coil becomes disconnected, the choke plate may stay closed much longer than it really needs to, thereby causing the engine to produce much more CO emissions and use much more fuel than is necessary. Disconnections or maladjustments of choke linkages can also contribute to high CO emissions, if such maladjustments prevent the choke from opening completely once the engine is warm. Maladjustments of the choke vacuum break can also contribute to high CO emissions, if they do not allow the choke to open when the engine is driving the car.

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* "Cold Temperature Emission Factors", Don E. Koehler, Energy Technology Center, Department of Energy, Bartlesville, Oklahoma, pg. 4.

2.2.2 Maladjustment of Idle Mixture

An idle mixture screw or screws are present on practically every vehicle that has a carburetor. The position of the screw controls the amount of fuel that is delivered to the engine while it is idling. On most pre-1981 model year vehicles, these screws are very easy to adjust or maladjust. On 1981 and later vehicles, however, the Parameter Adjustment Regulations require idle mixture to be non-adjustable.* Manufacturers have sealed the idle mixture screws after adjustment with metal caps or plugs. Adjustment of idle mixture after sealing is in most cases not necessary, however, it is possible.**

Maladjustments of idle mixture screws which cause lean mixtures in the engine are not very common because they cause poor driveability. The engine, being too lean, may misfire or stall. Maladjustments which cause rich mixtures are far more common, because many people feel that driveability may be improved with a richer idle mixture. (Actually, poor driveability can be the result of many different factors. Maladjustment of idle mixture is an easy task and performing the maladjustment can sometimes cover up for other problems which may be causing poor driveability.) A maladjustment of idle mixture which causes a rich mixture results in an engine producing high CO emissions. However, this fact has been noted mostly for vehicles tested at 75° in which the choke system was not required to operate for very long after starting. At this temperature, idle mixture can have a large percentage effect on total CO emissions if it is maladjusted. At colder temperatures, the percentage effect of idle mixture maladjustment on total CO emissions may be smaller. One purpose of this report is to investigate whether and by how much the effect of idle mixture maladjustments is affected by temperature.

If a vehicle which has a rich maladjustment of this idle mixture is started and operated in cold weather (20°F, for example), the resulting high CO emissions are caused by <u>both</u> choke operation and maladjusted idle mixture. It is likely that choke operation is the dominant factor in high CO emissions while the engine is cold, and that maladjusted idle mixture is the dominant factor when the engine is warmed-up and the choke is fully open. However, it is possible that a maladjusted idle mixture screw could cause additional cold start CO emissions above and beyond those produced as the result of choke operation.

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* 1979 and 1980 GM cars also have idle mixture screws which are sealed with metal plugs in recesses in the carburetor.

** The carburetors must first be removed, the caps or plugs are knocked off or drilled out, the carburetor is replaced on the engine and then adjustments can be performed.

2.2.3 Heated Air Intake Systems

The heated air intake system collects heated air from around the exhaust manifold of the engine and mixes it with cold air entering the air filter so that warmed air, instead of predominantly cold air, enters the carburetor to mix with fuel. The warmer air results in a larger fraction of the fuel being vaporized than would be the case if colder air were used. This allows total fuel delivery to be reduced without affecting driveability.

Officials from the State of Alaska have noticed that many in-use vehicles in Alaska have disconnected heated air intake systems. They are unsure as to whether the disconnects are deliberate or are the result of normal deterioration, but they suspect the latter reason because it does not make sense that people would deliberately disable their vehicles to obtain poorer cold weather driveability. EPA was unsure of the CO emission effects at cold temperatures of disconnecting the heated air intake system, so this maladjustment was added to the I/M effectiveness study, since a disconnected heated air intake system would be easy to spot in an I/M program that included an underhood inspection and since the repair is quite simple.

2.3 External Factors

Driving habits are external factors which can affect the amount of CO produced by vehicles at cold temperatures. Many people warm-up their cars at idle before embarking on a trip. During idle warm-up periods, the throttle linkage often engages a high idle cam, making an engine idle faster when warming up than when it is already warm. This is done to prevent stalling out and promote faster warm-up times. However, the fast idle speed is lower than the engine speed that would be used in driving the car. Also, there is no load on the engine when it is in the fast idle configuration. As a consequence, an engine warms up more slowly during an idle warm-up than it would if immediately driven. A longer warm-up time would seem to promote the production of more CO emissions. However, since the engine is not under load and is not operating at a higher speed, the volumetric flow rate of air and fuel through the engine is lower than it would be if the car were immediately driven. This would seem to decrease the amount of CO produced during idle warm-up as contrasted to driving immediately after start-up.

2.4 Technology Which Reduces Cold Start Emissions

2.4.1 New Technology

In recent years automobile manufacturers have made improvements in emission control and fuel delivery systems which have resulted in reduced cold start emissions. These improvements were in part motivated by the fact that manufacturers had to reduce CO emissions during the cold start portion of the 75° FTP certification test in order to meet progressively more stringent standards, particularly the 1981 light-duty vehicle (LDV) CO emission standard of 3.4 g/mi. Some of the most important improvements made by automobile manufacturers which have resulted in reduced cold start emissions are (1) early fuel evaporation systems which preheat the air/fuel mixture in the intake manifold in order to increase fuel evaporation and thereby improve cylinder-to-cylinder fuel distribution and allow total fuel delivery to be

reduced, (2) closer placement of catalysts to the engine to reduce catalyst warm-up time, (3) more precise fuel delivery systems such as intake port fuel injection or throttle body fuel injection and (4) closed loop computer control of fuel delivery via carburetor or injection systems. These latter systems, especially the fuel injection systems, deliver fuel to the engine in much more precise amounts depending on engine temperature, speed, load, and other engine operating variables.

2.4.2 Block Heaters

Block heaters have been in use for a long time. One of the most common types of block heaters is called the "frost plug heater." In this system, an electric heating element is placed in contact with the engine coolant. The element heats the coolant, thereby keeping certain parts of the engine such as the engine block or parts of the engine which have direct contact with the heated water significantly warmer than they would be without the heater.

There is little FTP data on the effects of block heaters on CO emissions. However, EPA-MVEL is currently conducting a study on three vehicles of the effect of a frost plug electric heater on CO emissions. The results of this study should be available within several months of the date at which this report is published.

2.5 Inspection/Maintenance Programs

An Inspection and Maintenance (I/M) program is a state or locally run program in which registered vehicles in certain urban areas are required to obtain and pass a tailpipe emission inspection periodically. Vehicles that have hydrocarbon (HC) or carbon monoxide (CO) emissions (at idle, 2500 rpm, and/or loaded cruise) which are greater than state or locally established emission standards are required to have maintenance to pass that standard.

The EPA has extensively studied the emission reduction potential of I/M. EPA's evaluation of 1975 through 1977 model year vehicles in the Portland, Oregon I/M program revealed that I/M was capable of reducing CO emissions from vehicles needing repair by about 50%. Put in terms of mass emission levels, the fleet of vehicles receiving repairs due to I/M underwent a 20 gm/mi CO emission reduction from about 40 gm/mi before I/M to about 20 gm/mi after I/M.* However, these tests were performed at 75°F. The emission reduction potential of I/M until recently has not been studied at colder temperatures. Vehicles with maladjusted idle mixture, which is the most common malmaintenance item in pre-1981 model year vehicle populations,** can be detected by Inspection and Maintenance (I/M) programs, since maladjustments of idle mixture cause high idle CO emissions, and these emissions can be detected by the idle analyzers used in all I/M programs. Most choke maladjustments

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* "Questions and Answers Concerning the Technical Details of Inspection and Maintenance", April, 1979, EPA-IMS-002/QA-1. Available on request from the I/M Staff, EPA, 2565 Plymouth Road, Ann Arbor, Michigan 48105.

** Vehicles with maladjusted idle mixture may be more common in cold weather climates than warm weather climates, since the maladjustments are thought to improve driveability, and driveability may be perceived to be a more frequent problem in a cold climate than a warm one.

probably cannot be detected by an idle analyzer, since vehicles are usually tested when fully warmed-up. However, when an underhood inspection is included in the I/M test, disconnected choke assist systems can be readily spotted. Therefore, I/M can reduce CO emissions from vehicles that have either maladjusted idle mixture or disconnected choke assists. There is nothing that I/M could or should do about high CO emissions which are the result of normal choke operation.

2.6 Notes on Test Procedures Used

The 1975 Federal Test Procedure (FTP) with minor modifications where necessary was used as the primary test cycle within this test program. The FTP requires vehicle exhaust emissions to be measured in three separate phases of a 31 minute typical urban driving cycle at 75°F. The distinction between phases is made to characterize the emissions produced from different modes of engine operation such as cold starting and engine warm-up plus possibly some stabilized operation, pure stabilized operation, and hot starting. The driving cycle of the FTP is presented graphically in Appendix 1.

These three phases of the FTP -- the cold transient phase, the cold stabilized phase, and the hot transient phase -- are sometimes referred to by their respective bag numbers (Bag 1, 2, and 3, respectively), since the emissions from each phase are collected in the different bags and analyzed separately.

The full FTP constitutes a trip distance of 11.1 miles. Emissions collected during the 11.1 mile trip are reweighted to reflect the average incidence of hot and cold starts (57% and 43%, respectively) and an average trip distance of 7.5 miles. However, the distance on Bag 1 (the cold start phase) is only 3.59 miles, and the distance of Bag 1 plus Bag 2 is 7.5 miles. Also, vehicles are always fully warmed-up prior to the end of the driving cycle on Bag 1, even when tested at temperatures of 20°F, so Bag 2 always represents stabilized operation. The comparatively short trip of Bag 1 represents a mix of cold and warm engine operation, with the mix of the two depending on temperature.

The 1975 FTP has only a 20 second cold idle warm-up included in the driving cycle. This is significantly shorter than would be expected in cold weather. Alaska officials conducted a study in their voluntary I/M program which revealed that many people in Alaska warm-up their cars at idle for between 2 and 5 minutes.* Therefore, for some phases of testing we added idle warm-up periods onto the driving cycle of the FTP in an attempt to more closely simulate cold weather driving.

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* The results of this study are tabulated in Appendix 2.

3.0 TEST PROGRAM DESCRIPTION

Ideally, the effectiveness of I/M should be evaluated by recruiting a large sample of in-use vehicles, testing them over the range of cold temperatures of interest, performing I/M-type repairs on the vehicles that would have failed a typical I/M test, and retesting the vehicles at cold temperatures. However, the resources to conduct this type of program were not available to EPA. The only alternative left was to take 4 cars, tune them to manufacturers specifications, test them at 20°F and 50°F, maladjust and disable them into a condition that might be expected of some in-use vehicles which would fail an I/M test, and retest them at 20°F and 50°F. I/M's effect on these vehicles could then be evaluated by comparing maladjusted emissions at 20°F and 50°F to the tuned-up emissions at 20°F and 50°F.

3.1 I/M Effectiveness Test Sequence

The test program used to evaluate I/M's effectiveness in cold temperatures is presented in Table 2.

Table 2

Test Sequence for I/M Effectiveness Study

1. Check tune-up specifications prior to testing
2. FTP @ 75°
3. 4-Mode Idle @ 75°
4. Cool to 50°
5. FTP @ 50°
6. 4-Mode Idle @ 50°
7. Cool to 50°
8. 5 min. idle @ 50°
9. LA-4* following 5 min. idle
10. Cool to 20°
11. FTP @ 20°
12. 4-Mode Idle @ 20°
13. Cool to 20°
14. 5 min. idle @ 20°
15. LA-4 following idle
16. Tune-up if maladjusted
17. FTP @ 75°
18. Maladjust vehicle (idle mixture, heated air intake, choke assist) and return to step 5.

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* An LA-4 is the driving cycle of the first two phases (cold transient and cold stabilized, i.e., Bag 1 and Bag 2) of the FTP.

Steps one through three were performed to assure that each test vehicle was operating properly. Steps four through eighteen represent all the tests performed on one vehicle in one configuration (i.e., tuned-up or maladjusted) at the two temperatures, 20°F and 50°F. The tests conducted at 50° represent an internal cycle which is repeated at 20°. Steps four through nine as a group is an example of this internal cycle; the rationale for using this particular sequence is as follows. The FTP (discussed in Section 2.3 and illustrated in Appendix 1), which is conducted first, combines a cold start (that is, driving almost immediately after the engine is started) with other phases of driving such as stabilized and hot start operation, and is the benchmark test procedure which is also used in certification of new vehicle prototypes. The 4-Mode idle is typical of an I/M test that could be conducted by an I/M program. It consists of Idle(N), 2500 rpm, Idle(N) and Idle(D). Emissions are sampled from the tailpipe with a garage infrared analyzer during all four test modes. The five minute idle warm-up followed by an LA-4 was conducted to simulate a cold climate driving cycle. The LA-4 (illustrated in Appendix 1) is very similar to the 1975 FTP, except that the hot-start (third) phase of operation is omitted.

3.2 Vehicles

The four vehicles used in this test program were a 1978 Ford LTD, a 1977 Chevrolet Nova, a 1980 Chevrolet Citation, and a 1980 Pinto. Specifications for the vehicles are listed in Appendix 3.

The Ford vehicles had air pumps with air pump control systems which routed pump air to the atmosphere (instead of to the exhaust manifold) after 1-2 minutes of engine operation at idle.

3.3 Controlled Environment Test Cell

The vehicles were tested in the Controlled Environment Test Cell (CETC) located in EPA's Motor Vehicle Emission Laboratory in Ann Arbor, Michigan. The cell contains a large roll electric dynamometer for simulating vehicle loads and inertia weights and a constant speed fan for engine cooling. A diagram of the cell is presented in Appendix 4. The cell is capable of maintaining any temperature between 20°F and 100°F throughout the duration of a test.

3.4 Maladjustments and Disablements

The idle mixture maladjustment was performed by first adjusting the idle mixture of the vehicles to zero-gain propane, or the point at which an injection of propane into the carburetor caused no increase in engine rpm. Then the screw was turned out one full turn. The heated air intake system was disabled by disconnecting the stove pipe from the exhaust manifold to the air filter. The choke assist system was disabled by disconnecting power to the thermostatic coil.

Throughout the remainder of this report, we will use the term maladjustments to mean both maladjustments and disablements.

3.5 Other Notes on Test Procedures

The starting procedures used during testing were the manufacturers' recommended cold start and warm start procedures. The cold start procedures for all vehicles required the driver to set the choke with the accelerator pedal prior to turning the key. The warm start procedures required the driver to turn the key without depressing the accelerator pedal.

A large fan was used to blow air over the test vehicles. The speed of the fan was controlled by the speed of the vehicles, so that the fan's speed increased with the speed of the test vehicle. A deflector was placed in front of the vehicle to prevent cooling air from the fan from passing over the vehicle when idle emissions were sampled.

In most instances a vehicle was allowed to "soak" overnight at the test temperature (20°F) so that there was reasonable assurance that all components (tires, oil, etc.) of a vehicle were at the test temperature. However, in order to expedite testing, a "forced cool down" technique was sometimes employed. In this cooling technique, fan speed was increased to approximately 55 mph while cell air was maintained carefully at 20°F. This reduced the "soak time" necessary to cool all components (including engine crankcase oil, which is the slowest component to cool) to 20° from about 12 hours (with no fan cooling) to about 4 hours. Vehicles were determined ready for testing when their engine crankcase oil temperature reached a value of 20$\pm$ 2°F.

4.0 RESULTS

4.1 Effects of Maladjustments on FTP Composite CO Emissions

The effect on FTP CO emissions of various maladjustments is illustrated in Table 3. Only three of the four vehicles received idle mixture maladjustment. The Citation, which had a sealed carburetor, did not. Therefore, emissions from the vehicles in this configuration are compared to tuned-up emissions from only these three vehicles which had the idle mixture maladjustment. The other two maladjustments included all four vehicles, therefore, a separate four vehicle average was computed for tuned-up emissions. This approach was used in analyzing all of the results related to I/M effectiveness. Each vehicle received one test at each configuration.

Table 3

Average FTP Composite CO Emissions (g/mi)
for Different Maladjustments

Configuration	Number of Vehicles In Sample	Test Temperature 20°F	50°F
Tuned-up	3	42.2 g/mi	22.8 g/mi
Malad. Idle Mix	3	66.0	47.9
Tuned-up	4	35.8 g/mi	19.8 g/mi
Disc. Choke Assist	4	195.4	108.6
Disc. Heated Air Intake	4	34.2	29.2

It is evident from Table 3 that vehicles in most maladjusted configurations emit substantially more CO emissions than when they are tuned-up. However, Table 3 also shows that CO emissions decreased at 20° when the heated air intake system was disabled.* Reasons for this behavior are discussed in Section 5.1. CO emissions from the vehicles with their choke assist systems

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* The same relationship was not observed in the average values at 50°F. However, 3 out of the 4 test vehicles experienced a reduction in FTP CO emissions at 50° when the heated air intake system was disabled. The average value reflected an increase because one vehicle experienced a very large increase in CO emissions. See Table 1 in Appendix 4 for individual vehicle results.

disconnected are very high. The technicians driving these test vehicles reported very poor driveability of the vehicles when this maladjustment was performed. Consequently, we do not expect too many people to disconnect their choke assist systems to improve driveability in cold weather. Therefore, we will concentrate the discussion of the results of other test cycles mainly around the most common maladjustment, idle mixture, and to a lesser extent on the disconnected heated air intake system.

4.2 Effects of Maladjustments on FTP Bag 1 CO Emissions

The driving cycle of Bag 1 of the FTP is 3.59 miles, so this comparison is relevant for those vehicles in a cold weather area where vehicles only travel about this distance and are not allowed to warm-up at idle first. Table 4 presents data illustrating the effects of the maladjustments on Bag 1 CO emissions.

Table 4

Average Bag 1 CO Emissions (g/mi)
for Different Maladjustments

Configuration	Number of Vehicles In Sample	Test Temperature 20°F	50°F
Tuned-up	3	131.9 g/mi	90.1 g/mi
Malad. Idle Mix	3	144.2	138.5
Tuned-up	4	114.7 g/mi	78.0 g/mi
Disc. Choke Assist	4	286.8	229.8
Disc. Heated Air Intake	4	112.8	98.8

Although the effect on Bag 1 emissions at 20°F is not as pronounced as it was for FTP composite CO emissions, it is evident that vehicles in maladjusted configurations emit more CO emissions from the driving cycle of Bag 1 than when they are tuned-up. At 50°F the CO reduction is greater going from the maladjusted idle mixture state to the tuned-up state than at 20°. Reasons for this behavior are discussed in Section 5.1.

4.3 Effects of Maladjustments on Idle Warm-Up Plus Bag 1 CO Emissions

This comparison is relevant to a cold weather driving cycle in a similar manner to the previous one, except that the driving cycle over which emissions were collected included a five minute idle warm-up period. Therefore, this comparison relates to those vehicles in a cold weather area that only travel about three or four miles but are allowed to warm-up at idle for five minutes prior to travelling.

The results in Table 5 are presented in g/mile. Although no miles are travelled during an idle warm-up, CO emissions are produced. Therefore, we added the mass emissions from the idle warm-up to the mass emissions from Bag 1, and divided the total by the number of miles travelled over the driving cycle for Bag 1, which is 3.59 miles.

Table 5

Average Idle Warm-Up Plus Bag 1
CO Emissions (g/mi) for Different
Maladjustments

Configuration	Number of Vehicles In Sample	Test Temperature 20°F	50°F
Tuned-up	3	111.9 g/mi	32.4 g/mi
Malad. Idle Mix	3	133.8	79.5
Tuned-up	4	93.6 g/mi	32.1 g/mi
Disc. Choke Assist	4	382.0	230.4
Disc. Heated Air Intake	4	98.9	45.0

Once again, CO emissions from the vehicles in maladjusted configurations are substantially higher than CO emissions from the vehicles in tuned-up configurations, with the exception of the disconnected heated air intake systems at 20°.

4.4 Effects of Maladjustments on Idle Warm-Up Plus Bag 1 and 2 CO Emissions

This comparison is relevant to a cold weather driving cycle that consists of a short idle warm-up (5 min.) and a subsequent trip which is longer than the one in Section 4.3 (7.5 as opposed to 3.6 miles). The results are presented in Table 6.

Table 6

Average Idle Warm-Up Plus Bag 1 and 2
CO Emissions (g/mi) for Different
Maladjustments

Configuration	Number of Vehicles In Sample	Test Temperature 20°F	50°F
Tuned-up	3	62.8 g/mi	32.2 g/mi
Malad. Idle Mix	3	107.3	75.4
Tuned-up	4	52.1 g/mi	28.2 g/mi
Disc. Choke Assist	4	280.7	174.2
Disc. Heated Air Intake	4	67.6	45.1

CO emissions from most of the maladjusted configurations are significantly higher than in the tuned-up configuration. The disconnected heated air intake is again the only exception.

4.5 Effects of Idle Warm-Up on Trip CO Emissions

In section 2.3 we discussed the factors that would affect whether CO emissions would be higher from a trip if an idle warm-up period were added. Table 7 presents a comparison of the results of the vehicles in tuned-up configuration for the Bag 1 test cycle with a 5 minute idle warm-up as compared to the Bag 1 test cycle without an idle warm-up.

Table 7

Average CO Emissions for Trip
Without 5 Minute Idle Warm-Up
and Trip with 5 Minute Idle Warm-Up

Test Cycle	Number of Vehicles	20°F	50°F
5 min. Idle Warm-Up + Bag 1	4	407 gms.	191 gms.
Bag 1 Only	4	412	280

At 20°F, there appears to be very little difference in trip emissions between the idle warm-up case and the non-idle warm-up case. At 50°F, the idle warm-up case results in less CO emissions for the trip. It is unlikely that anyone would regularly warm-up their car at idle at 50° F.

4.6 Effects of Maladjustments on Fuel Consumption

The fuel consumption data is presented in such a way to contrast fuel consumption from Bag 1 without an idle warm-up period to fuel consumption from an idle warm-up plus Bag 1. This will illustrate the differences in fuel consumption due to different cold weather driving cycles for a short trip (3.59 miles). The data are presented in Tables 8 and 9; other fuel consumption data is presented in Appendix 5.

Table 8

FTP Bag 1 Fuel Consumption (gals.)
Without Idle Warm-Up

Configuration	Number of Vehicles In Sample	Test Temperature 20°F	50°F
Tuned-up	3	.30 gals.	.26 gals.
Malad. Idle Mix	3	.30	.28
Tuned-up	4	.27 gals.	.24 gals.
Disc. Choke Assist	4	.38	.32
Disc. Heated Air Intake	4	.27	.24

Table 9

Idle Warm-Up Plus Bag 1
Fuel Consumption (gals.)

Configuration	Number of Vehicles In Sample	Test Temperature 20°F	50°F
Tuned-up	3	.38 gals.	.31 gals.
Malad. Idle Mix	3	.39	.39
Tuned-up	4	.34 gals.	.29 gals.
Disc. Choke Assist	4	.53	.43
Disc. Heated Air Intake	4	.36	.36

Generally, fuel consumption is higher (for both Tables 8 and 9) in the maladjusted configurations than the tuned-up configurations. In no case did a maladjustment decrease fuel consumption. Tables 8 and 9 also indicate that fuel consumption is higher when vehicles are warmed-up at idle than when they are not warmed-up.

4.7 Four Mode Idle Test Results

The results from the idle (N) mode which came after the 2500 rpm preconditioning period for the Four Mode Idle Test are presented in Appendix 7. Of the three vehicles that received the idle mixture maladjustment, all three would have been detected by an I/M program with a cutpoint for these vehicles of 3.0% CO or less.

5.0 CONCLUSIONS

Inasmuch as this test program was limited to four vehicles, these conclusions should be viewed as preliminary. EPA loaned the Mobile Emissions Test Facility (METFac) to the Alaska Department of Environmental Conservation (ADEC) for the purpose of studying I/M effectiveness in cold weather. During the 1981-82 winter, the METFac test program recruited in-use vehicles and tested them as received, not in deliberately maladjusted configurations. Consequently, the results from the ADEC program will be a more realistic indicator of how an I/M program could reduce CO emissions in a cold climate. The METFac program also tested a larger sample of vehicles.

The results of this test program indicated that for all test cycles used, reductions in CO emissions occurred when vehicles with maladjusted idle mixture and disconnected choke assists were tuned-up. This relationship did not necessarily occur with the repair of the disconnected heated air intake system. One explanation for this result might be that disablement of the heated air intake system causes colder, denser, air to pass through the carburetor, resulting in leaner air/fuel mixtures than would be the result if the heated air intake system were not disabled. The leaner mixtures would result in lower CO emissions. Driveability might suffer since fuel vaporization would be worse with the colder air, causing lean misfires. Such misfires would not increase CO emissions, however.

The data in Section 4 illustrate that Bag 1 CO emissions from a vehicle with maladjusted idle mixture are predominantly but not exclusively caused by normal choke behavior. For example, in Table 5 (page 17) at 50°F the tuned-up CO emissions on three vehicles are 60.5 g/mi. At 20° F, the tuned up emissions are 138.4 g/mi, reflecting more choke action. At 20° in the maladjusted idle mixture configuration, the CO emissions are 164.9 g/mi, reflecting both increased choke and the maladjustment. Consequently, if a vehicle has maladjusted idle mixture, a significant portion of Bag 1 CO emissions will be due to the maladjustment, not just choke behavior. This means that I/M could be effective at reducing CO emissions from short trips in cold climates as well as from longer trips in moderate and warm climates.

5.1 Differences in CO Reductions at 20° F and 50° F

For the FTP composite and 5 minute plus FTP Bag 1 and 2 test cycles, the CO g/mi reductions obtained in going from the maladjusted to the tuned-up configuration for 20° and 50° are approximately the same. These data, along with the FTP Bag 1 and idle warm-up plus FTP Bag 1 test cycle data, are presented in Table 10.

Table 10

CO Reductions Obtained in Going
From Maladjusted Idle Mixture Configuration
to Tuned-Up Configuration: Average of 3 Vehicles

Test Cycle	Distance	g/mi. Reductions 20°F	50°F
FTP Composite	7.5 miles	23.8 g/mi	25.1 g/mi
FTP Bag 1 Only	3.59	12.3	48.4
5 min. Idle Warm-Up + FTP Bag 1	3.59	40.2	47.1
5 min. Idle Warm-Up + FTP Bag 1 + Bag 2	7.5	44.5	43.2

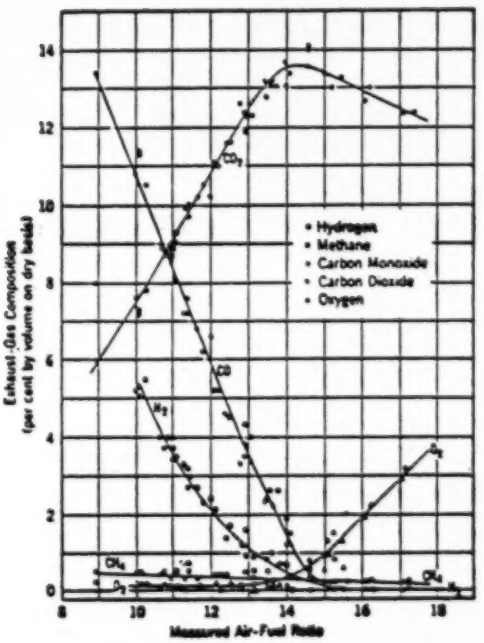
For the longer distance test cycles of the FTP composite and 5 minute idle + Bag 1 + Bag 2, the CO reductions at 20° F are about the same as at 50° F. At the shorter test cycles (FTP Bag 1 and 5 minute idle plus FTP Bag 1), the CO reductions due to correcting malajusted idle mixture are smaller at 20° F than they are at 50° F. These trends are understandable, if it can be demonstrated that an idle mixture maladjustment has a smaller g/mi impact on an engine when it is in a choking mode than when it is in a warm stabilized mode. If this is true, then the shorter test cycles' comparative lack of warm stabilized operation would explain the smaller g/mi effect of maladjustment in these cycles. The problem then is to explain why an idle mixture maladjustment should have only a small effect when the choke is engaged.

We know that choke behavior during cold start delivers extra fuel to the engine causing corresponding increases in CO emissions. We also know that maladjusting idle mixture also adds extra fuel to the engine, even during choke-on conditions, presumably resulting in higher CO emissions. The question then centers on why CO emissions due to maladjusted idle mixture are not as high during cold start as they are during stabilized operation.

The answer to this question can be found in examining the effects of choke benavior and maladjusted idle mixture on the air/fuel ratio. Figure 1 shows the effects of changing air/fuel ratio on exhaust gas composition. On the rich side of stoicheometry (approximately 14.7/1), CO concentration is linearly dependent on air/fuel ratio.

Figure 1

Exhaust Gas Composition Vs.
Measured Air/Fuel Ratio, For
Unsupercharged Automotive
Engines*



Our hypothesis is that at stabilized or warm engine temperatures when an engine is running at stoichiometric or leaner, maladjusting idle mixture causes a significant decrease in air/fuel ratio, resulting in a significant increase in CO emissions. In Figure 1, this situation might be represented by the CO emission increase in going from an air/fuel ratio of 14.7 to 13, a decrease of 1.7 in the air fuel ratio. Conversely, when the engine is cold and the choke is operating, the air/fuel ratio is already very low even if the idle mixture is correctly adjusted. We suspect that maladjusting idle mixture causes almost the same amount of excess fuel to reach the engine when the engine is cold as when it is warm. However, because the denominator (fuel) of the air fuel ratio is already so large when the engine is cold due to choking action, the same excess fuel from the idle mixture maladjustment causes a smaller decrease in air/fuel ratio when the engine is cold than when the engine is warm. In Figure 1, this situation might be represented by an

* From Emissions from Combustion Engines and Their Control, D.J. Patterson and N.A. Henein, Ann Arbor Science Publishers, 1979, pg. 99.

initial air/fuel ratio with the choke operating at about 12; with the addition of the idle mixture maladjustment the air/fuel ratio might only drop 1.2 points to 10.8, versus the drop of 1.7 cited earlier.* Consequently, the reduction in air/fuel ratio and corresponding increase in CO emissions is not as large at cold engine temperatures as at warm engine temperatures. This effect is rather slight, leaving room for the possibility that in fact maladjusting the idle mixture causes a smaller amount of excess fuel to reach the engine when it is cold.

Whether an idle mixture maladjustment causes the same or less excess fuel to reach a choked engine as a warm engine has not yet been settled by this discussion. Given the changes in intake vacuum patterns that occur with choking, it is certainly conceivable that less excess fuel comes through the idle circuit. If it is true that maladjusting the idle mixture causes less excess fuel for cold engines than it does for warm engines, then our test data should show a larger fuel consumption difference between maladjusted and tuned-up configurations at 50° F than at 20° F. Fuel consumption data for the FTP Bag 1 and 5 minute idle warm-up plus FTP Bag 1 at 20° and 50° are presented in Table 11.

Table 11

Fuel Consumption Going from Maladjusted and Tuned-Up Configurations, Average of Three Vehicles

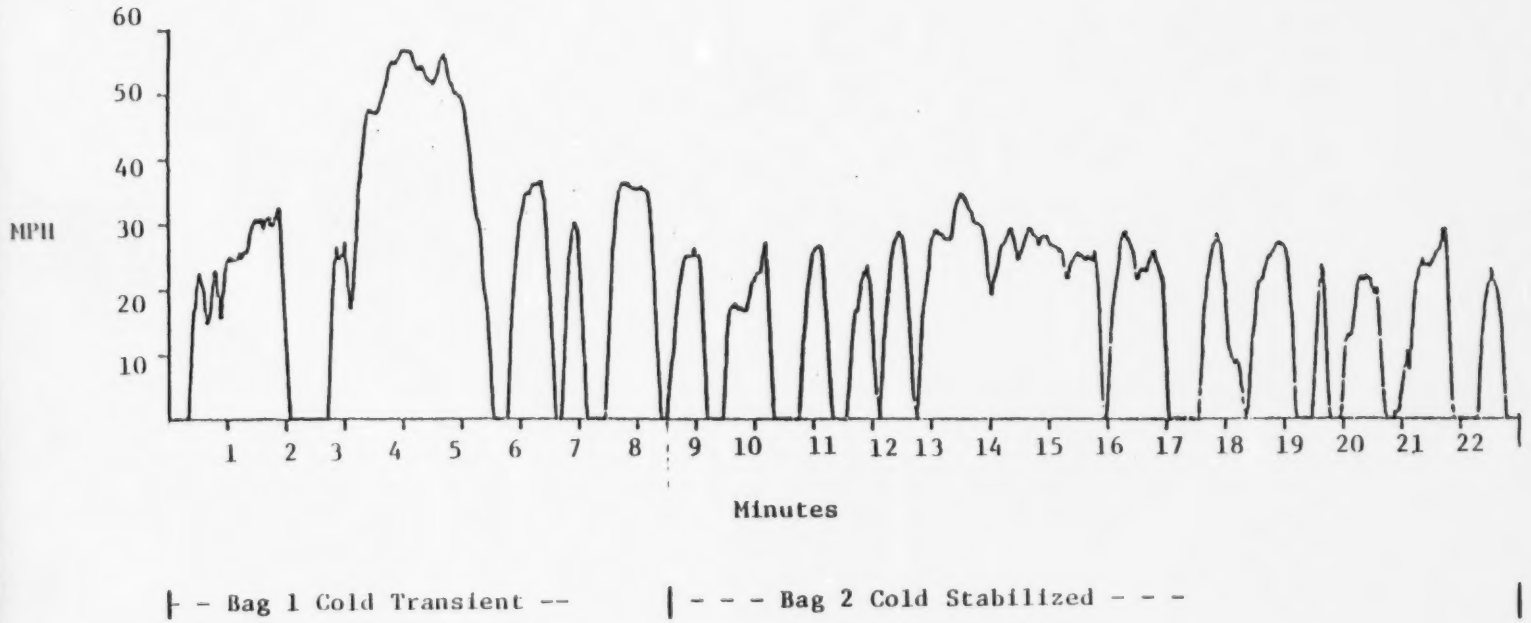
Test Cycle	Configuration	Fuel Consumption (gals.) 20°	50°
FTP Bag 1	Maladjusted	.303 gals.	.283 gals.
	Tuned-up	.303	.260
Idle warm-up plus FTP Bag 1	Maladjusted	.390 gals.	.390 gals.
	Tuned-up	.383	.313

The data in Table 11 confirm our hypothesis, since there is a greater fuel consumption difference between maladjusted and tuned-up configurations at 50°F than at 20°F.

* Further explanation: Assume 14.7 units of air and 1 unit of fuel during warm operation with a properly adjusted idle mixture. An idle mixture maladjustment might increase fuel delivery by 0.131 units, reducing the A/F ratio to 13. Choke operation might increase fuel delivery by 0.225 units, for an A/F ratio of 12. Both choke and idle mixture might increase fuel delivery 0.356 units, for an A/F ratio of 10.8.

APPENDICES

Urban Dynamometer Driving Schedule
(LA-4)



Explanation

Pictured are the driving cycles of Bags 1 and 2 of the FTP. This portion is referred to as the LA-4, or Urban Dynamometer Driving Cycle. The 1975 FTP adds a 10 minute engine-off period (referred to as a "hot soak") after Bag 2, followed by the Bag 1 driving cycle which is then referred to as Bag 3 (hot transient). In some of our tests, we also used a "Bag 4", which was the Bag 2 driving cycle repeated after Bag 3.

Appendix 2

The following questions, among others, were asked of 500 participants in the 1979-80 Anchorage Free Emission Control Test (AFECT), eliciting these responses:

How long do you let the vehicle warm up in the morning on cold mornings after starting the vehicle for the first time?

How long do you let the vehicle warm up after work during cold days?

When you are shopping and leave the store, how long do you warm up the vehicle before driving it?

MINUTES	WARM-UP TIME - AM %	CUMULATIVE %	WARM-UP TIME - PM %	CUMULATIVE %	WARM-UP TIME - POST SHOPPING %	CUMMULATIVE %
0	8.9	8.9	14.3	14.3	36.0	36.0
0.5	10.0		11.6		22.2	
1.0	8.9		15.8		17.3	
1.5	3.9		5.8		4.5	
2.0	9.0	41.1	10.7	58.2	8.1	88.1
2.5	3.5		3.0		0.6	
3.0	6.1		5.8		2.9	
3.5	3.8		2.6		0.4	
4.0	3.9		3.2		0.1	
4.5	0.2		0.2		6.2	
5.0	17.3	75.5	15.0	88.0	4.5	98.0
5.5	0.0		0.0		--	
6.0	0.2		0.2		--	
6.5	0.7		0.2		--	
7.0	0.0		0.2		--	
7.5	5.1		2.4		--	
8.0	0.0		0.0		--	
8.5	0.0		0.0		--	
9.0	0.4		0.4		--	
10.+	18.0		8.8		2.0	

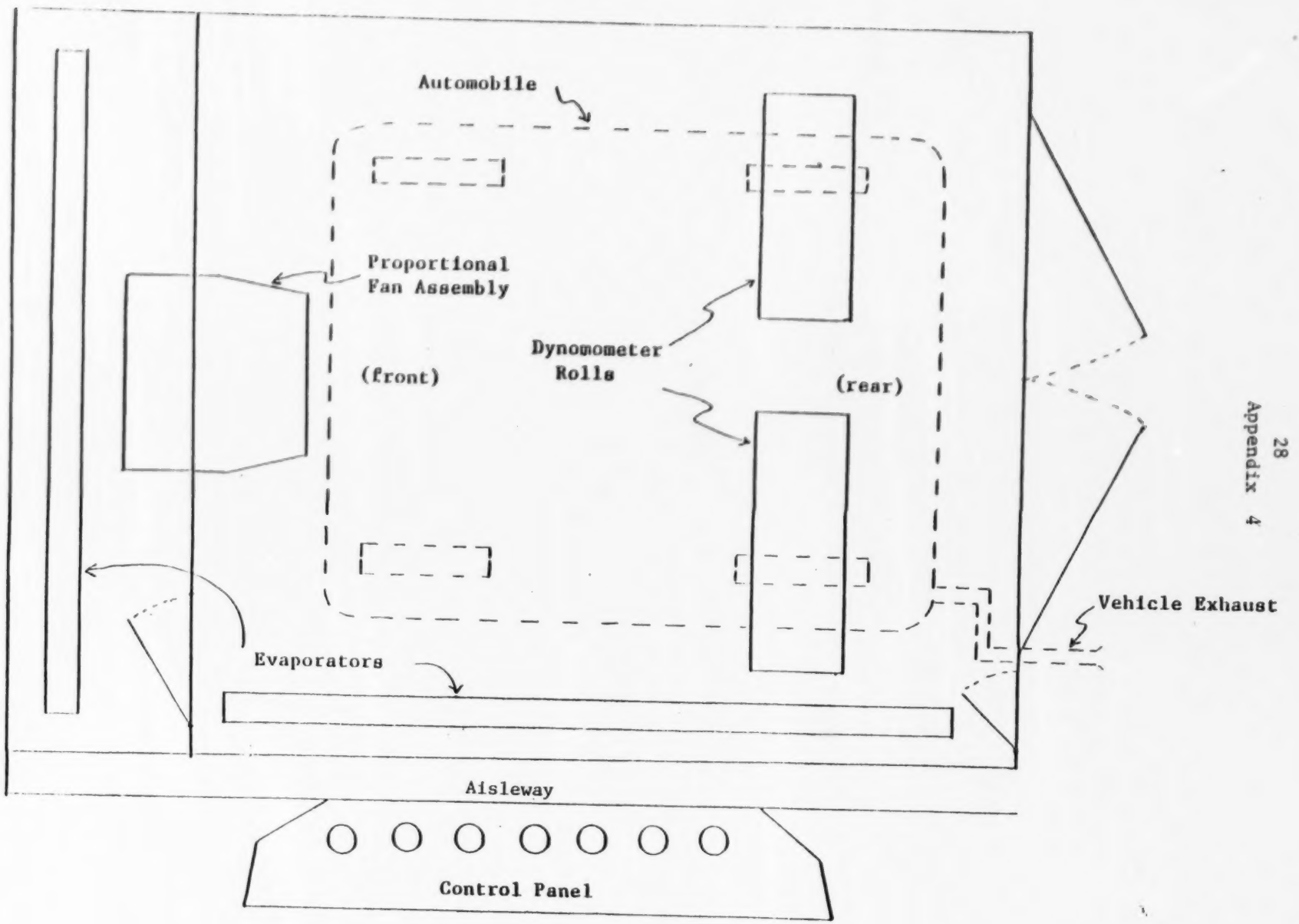
Appendix 3

Test Vehicle Specifications

	Ford LTD	Nova	Citation	Pinto
Year	1978	1977	1980	1980
Emission Control System	EGR, Air pump, oxid. cat.	EGR, oxid. cat.	EGR, pulse-air, 3-way cat., closed loop fuel control	EGR, pulse-air, oxid. cat.
Engine Configuration	V-8	I-6	I-4	I-4
Displacement	302 CID	250 CID	2500 CC	2.3L(140CID)
VIN	F8863F182034F	1X27D7W100815	1X685AW140457	0T11A114948
Inertia Weight	4500	3500	2750	2750
Actual Horsepower Setting	10.9	11.2	7.3	9.7

Indolene HO was used as a test fuel on all vehicles at all temperatures.

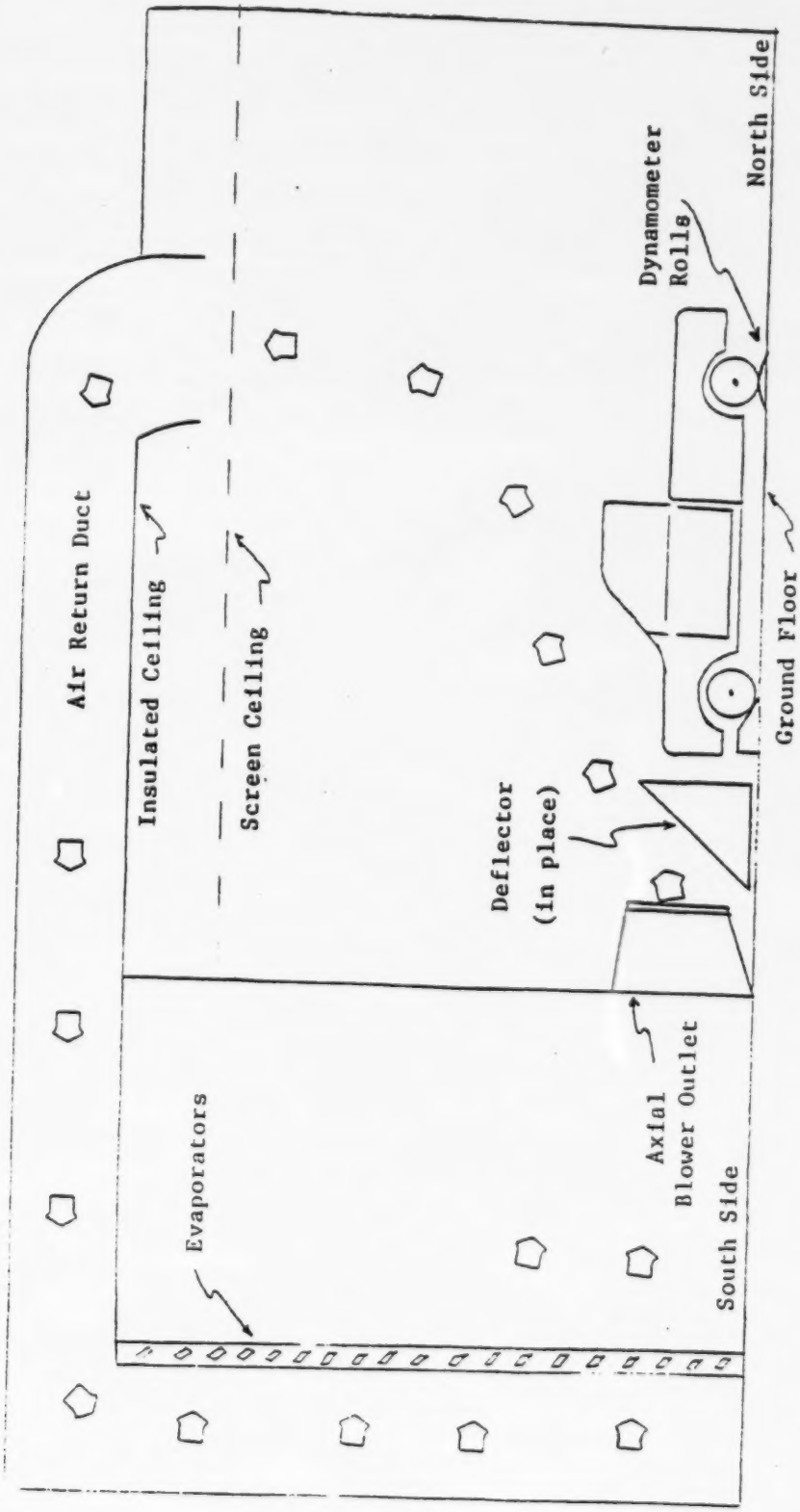
Controlled Environment Test Cell
Environmental Protection Agency



Appendix 4 (continued)

Controlled Environment Test Cell

U.S. Environmental Protection Agency



AXIAL AIR FLOW DIAGRAM

Appendix 5

Individual Vehicle CO Emission Results

Table 1
FTP Composite CO Emissions (gm/mi)

	20°F				50°F			
Configuration	LTD	Nova	Citation	Pinto	LTD	Nova	Citation	Pinto
Tuned-Up	52.8	29.1	16.5	44.9	35.9	21.7	11.2	10.7
Malad. Idle CO	88.1	43.8	*	66.1	88.1	38.0	*	17.6
Disc. Choke Assem.	54.6	427.5	133.7	165.8	57.4	266.6	51.0	59.4
Disc. Heat Intake	49.8	27.4	17.2	42.5	56.5	20.2	9.5	10.6

Table 2
FTP Bag 1 CO Emissions (gm/mi)

	20°F				50°F			
Configuration	LTD	Nova	Citation	Pinto	LTD	Nova	Citation	Pinto
Tuned-Up	239.3	96.3	63.1	60.2	155.8	66.8	41.4	47.9
Malad. Idle CO	253.2	103.9	*	75.5	288.4	72.7	*	54.4
Disc. Choke Assem.	252.7	410.0	264.3	220.1	260.8	401.4	113.4	143.6
Disc. Heat Intake	227.6	93.0	66.8	63.7	253.3	60.7	31.8	49.5

Table 3
Idle Warm-Up + Bag 1 CO Emissions
(gm/mi.)

	20°F				50°F			
Configuration	LTD	Nova	Citation	Pinto	LTD	Nova	Citation	Pinto
Tuned-Up	131.5	104.8	38.7	99.3	37.3	35.0	30.8	25.1
Malad. Idle CO	157.6	124.3	*	119.6	101.7	83.4	*	53.4
Disc. Choke Assem.	190.6	657.9	320.3	359.2	82.3	454.2	200.4	184.7
Disc. Heat Intake	127.2	106.8	55.9	105.5	56.0	39.0	25.2	59.9

* Idle mixture was not maladjusted on this vehicle because it had a sealed idle mixture screw.

Table 4
Idle Warm-Up + Bag 1 and 2 CO Emissions
(gm/mi.)

	20°F				50°F			
Configuration	LTD	Nova	Citation	Pinto	LTD	Nova	Citation	Pinto
Tuned-Up	64.0	57.1	20.3	67.2	59.2	23.2	16.3	14.2
Malad. Idle CO	150.0	76.6	*	95.3	138.0	57.5	*	30.6
Disc. Choke Assem.	112.8	556.8	190.0	263.3	107.8	355.4	121.7	111.9
Disc. Heat Intake	109.2	59.6	28.5	73.4	106.1	25.0	20.1	29.1

* Idle mixture was not maladjusted on this vehicle because it had a sealed idle mixture screw.

Appendix 6

Individual Vehicle Gas Mileage and Fuel Consumption Results

Table 1
FTP Composite Fuel Economy
(mpg)

	20°F				50°F			
Configuration	LTD	Nova	Citation	Pinto	LTD	Nova	Citation	Pinto
Tuned-Up	12.2	17.0	22.5	19.7	13.3	18.4	24.1	21.9
Malad. Idle CO	10.4	17.0	*	19.5	10.9	17.9	*	20.8
Disc. Choke Assem.	12.2	6.8	15.6	15.0	13.1	10.2	20.4	16.9
Disc. Heat Intake	12.3	17.0	19.8	20.7	12.7	18.4	24.0	22.5

Table 2
FTP Bag 1 Fuel Consumption (gals.) Without Idle Warm-Up

	20°F				50°F			
Configuration	LTD	Nova	Citation	Pinto	LTD	Nova	Citation	Pinto
Tuned-Up	.41	.29	.19	.21	.34	.24	.16	.20
Malad. Idle CO	.42	.27	*	.22	.42	.24	*	.19
Disc. Choke Assem.	.42	.51	.31	.29	.39	.45	.20	.23
Disc. Heat Intake	.40	.27	.22	.21	.39	.23	.16	.19

Table 3
Idle Warm-Up Fuel Consumption + Bag 1 Fuel Consumption

	20°F				50°F			
Configuration	LTD	Nova	Citation	Pinto	LTD	Nova	Citation	Pinto
Tuned-Up	.44	.42	.22	.29	.33	.40	.23	.21
Malad. Idle CO	.44	.43	*	.30	.43	.46	*	.28
Disc. Choke Assem.	.47	.79	.45	.41	.36	.69	.30	.35
Disc. Heat Intake	.45	.42	.26	.32	.35	.45	.39	.23

* Idle mixture was not maladjusted on this vehicle because it had a sealed idle mixture screw

Appendix 7

Four Mode Idle Test
Results - Second Idle N Mode Tabulated

(Idle N-2500 RPM - Idle N - Idle D)

Temperature = 20° F

	LTD		Nova		Citation		Pinto	
Configuration	HC	CO	HC	CO	HC	CO	HC	CO
Tuned-Up	95ppm	0.03%	180ppm	1.5%	10ppm	0.1%	160ppm	0.8%
Malad. Idle CO	115	3.2	420	3.7	*	*	700	5.1
Disc. Choke Assem.	110	0.03	175	1.7	10	0.03	320	0.7
Disc. Heat Intake	110	0.02	500	6.2	10	0.01	275	6.8

Temperature = 50°

	LTD		Nova		Citation		Pinto	
Configuration	HC	CO	HC	CO	HC	CO	HC	CO
Tuned-Up	95ppm	0.02%	180ppm	0.8%	00ppm	0.0%	15ppm	0.02%
Malad. Idle CO	125	3.8	400	3.5	*	*	330	3.2
Disc. Choke Assem.	60	0.03	185	1.1	00	00	330	3.2
Disc. heat Intake	150	0.02	330	5.1	5	0.0	20	0.05

* Idle mixture was not maladjusted on this vehicle because it had a sealed idle mixture screw.